Short-term radiation anomalies and feedbacks observed by CERES

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CERES Science Team Meeting

Geophysical Fluid Dynamics Laboratory

Princeton, NJ, October 22-25, 2012

Introduction

➢ Climate state and radiation

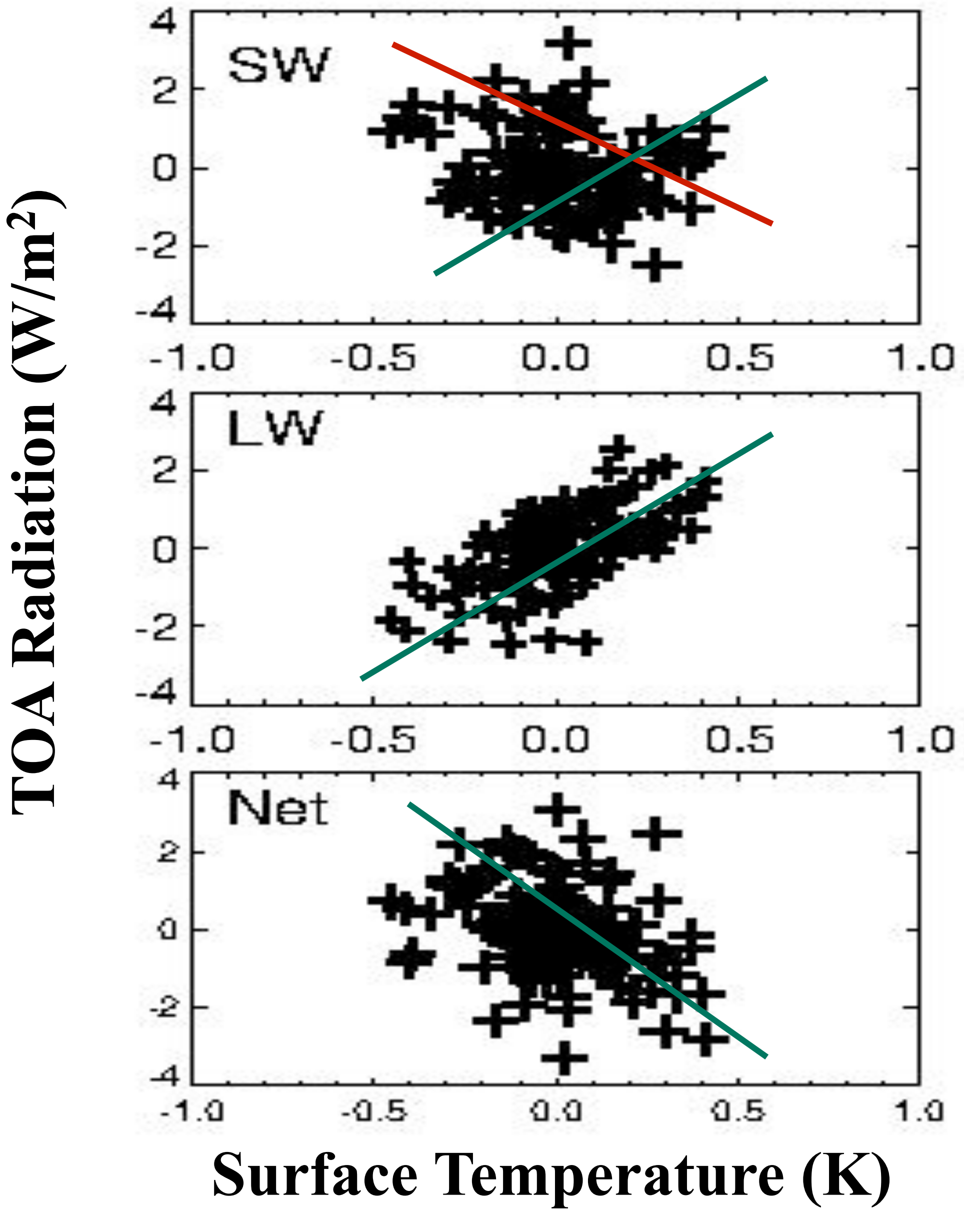
- ❖ variations in climate states drive radiation changes
- ❖ changes in radiation lead climate state variations

Chicken and Egg problem

➢ Climate Studies

- ❖ most efforts focus on radiation & surface temperature
  difficulties: no clear signals, various kinds of processes
  dynamics/thermodynamics, especially in short time scales

10-yr TOA Radiation Anomaly



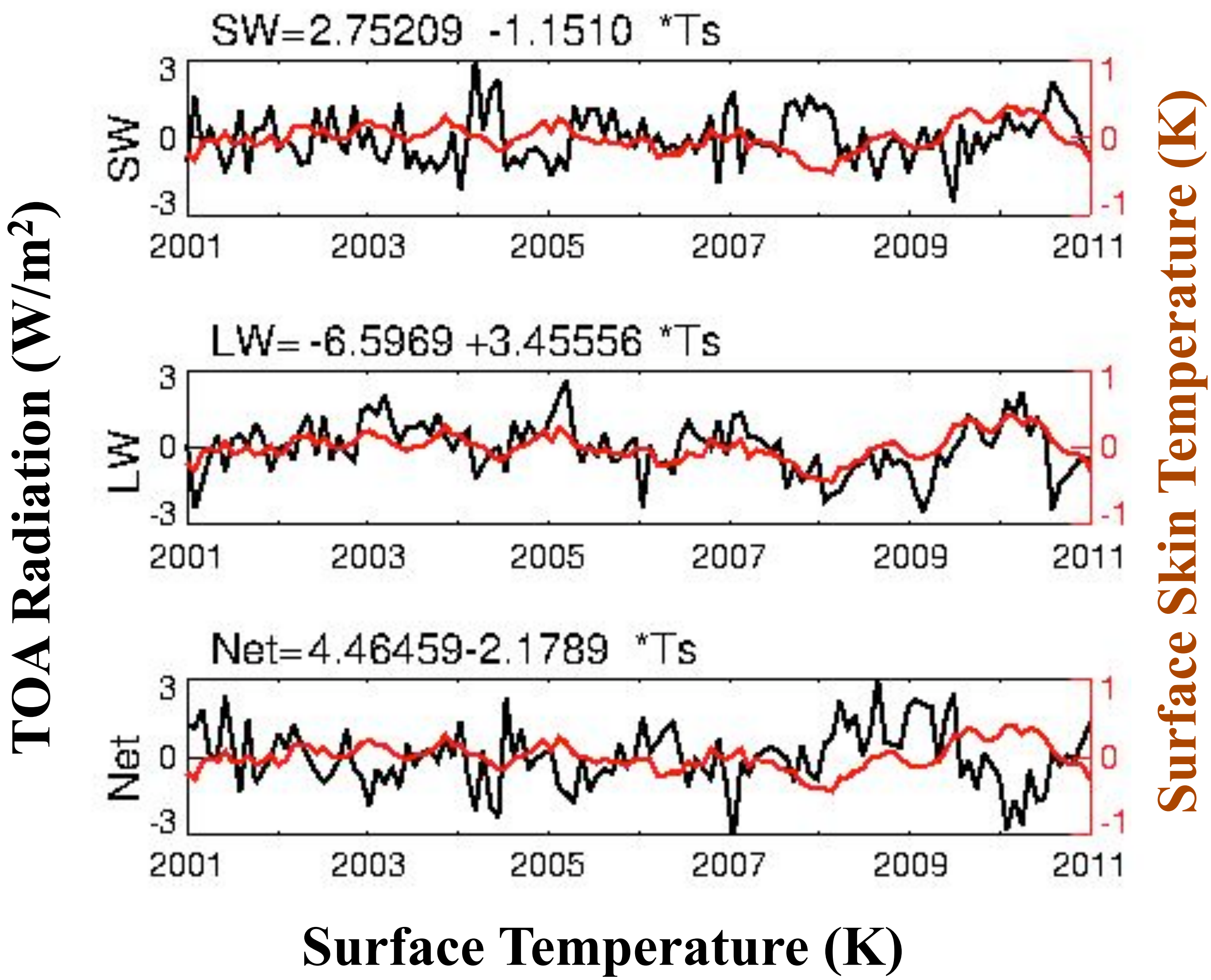
Reflected SW
$SW = 2.75 – 1.15Ts$

Outgoing LW
$LW = -6.60 + 3.46Ts$

Net Incoming
$Net = 4.46 – 2.18Ts$

Strip features: chaotic processes

Observed Ts vs Radiation



Introduction

➢Climate Studies

❖ most efforts focus on radiation & surface temperature
difficulties: no clear signals, various kinds of processes
dynamics/thermodynamics, especially in short time scales

➢ Cloud observations

❖ clouds could be used to estimate radiation fields

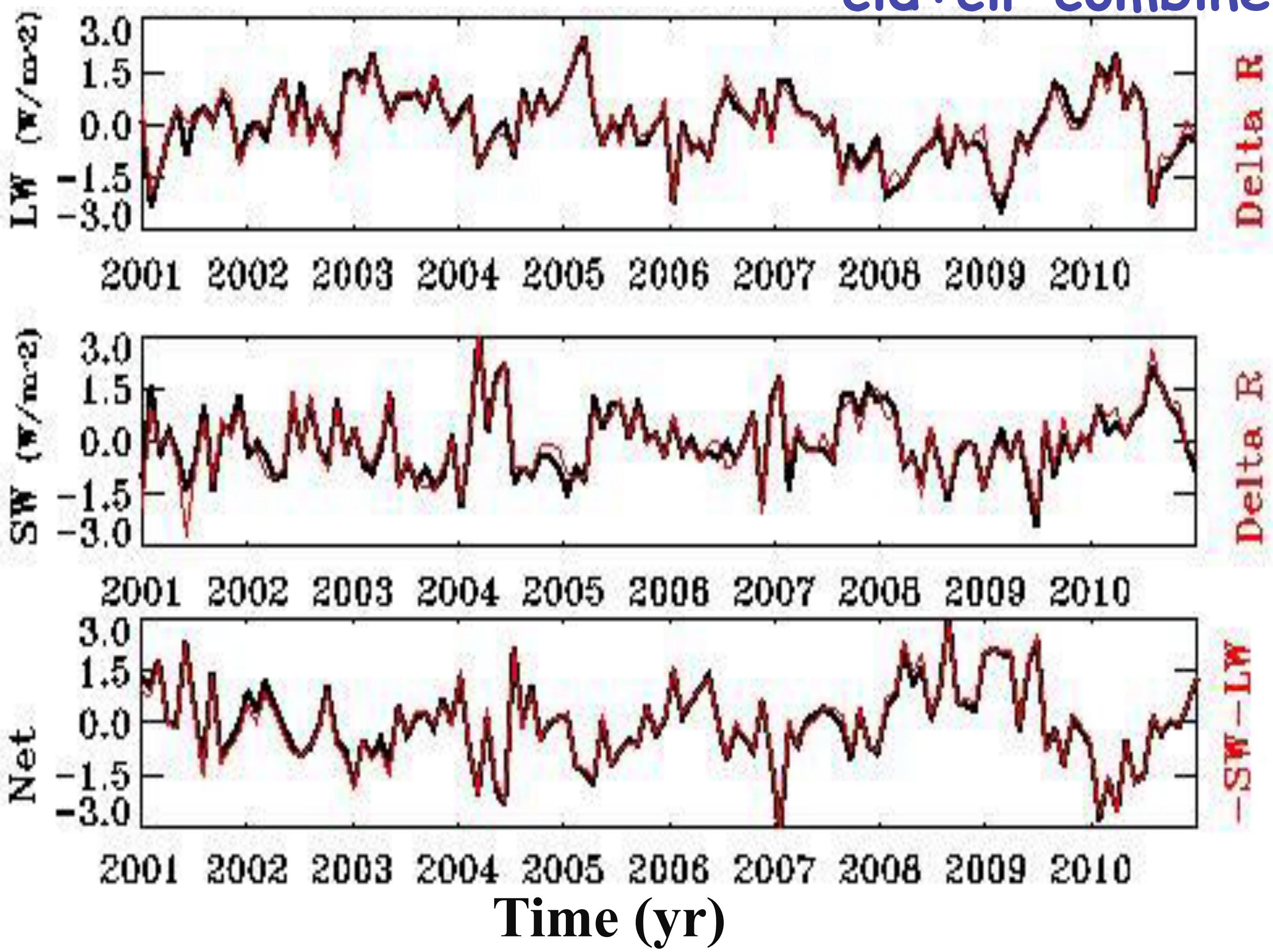
However: model cannot predict clouds accurately
at lease currently

clouds <<<<<< >>>>>>> radiation

the problem in different aspects

radiation anomaly

cld+clr combined



$$\Delta R \approx -\Delta c\, R_{clr} + (1-c)\Delta R_{clr} + \Delta c R_{cld} + c\, \Delta R_{cld}$$

Goals

- **Understanding radiation variations**
  - maintaining its base state: especially from LW anomaly
  - relationship with other processes

- **Short-term phenomena**
  - long-term effect may not show up clearly
  - short-term feedback from dynamics/thermodynamics

- **Many controlling variables**

Radiation Perturbation & Basic Climate Response

$$Rnet = (1-\alpha)So - \varepsilon\sigma Ts^4$$

equilibrium state: $\Delta\alpha = \Delta\varepsilon = 0$

$$\Delta Rnet = -\frac{4\varepsilon\sigma Ts^4}{Ts}\Delta Ts$$

feedbacks: related to this effect.

$$= -\frac{4\times 237}{288}\Delta Ts = -3.3\Delta Ts$$

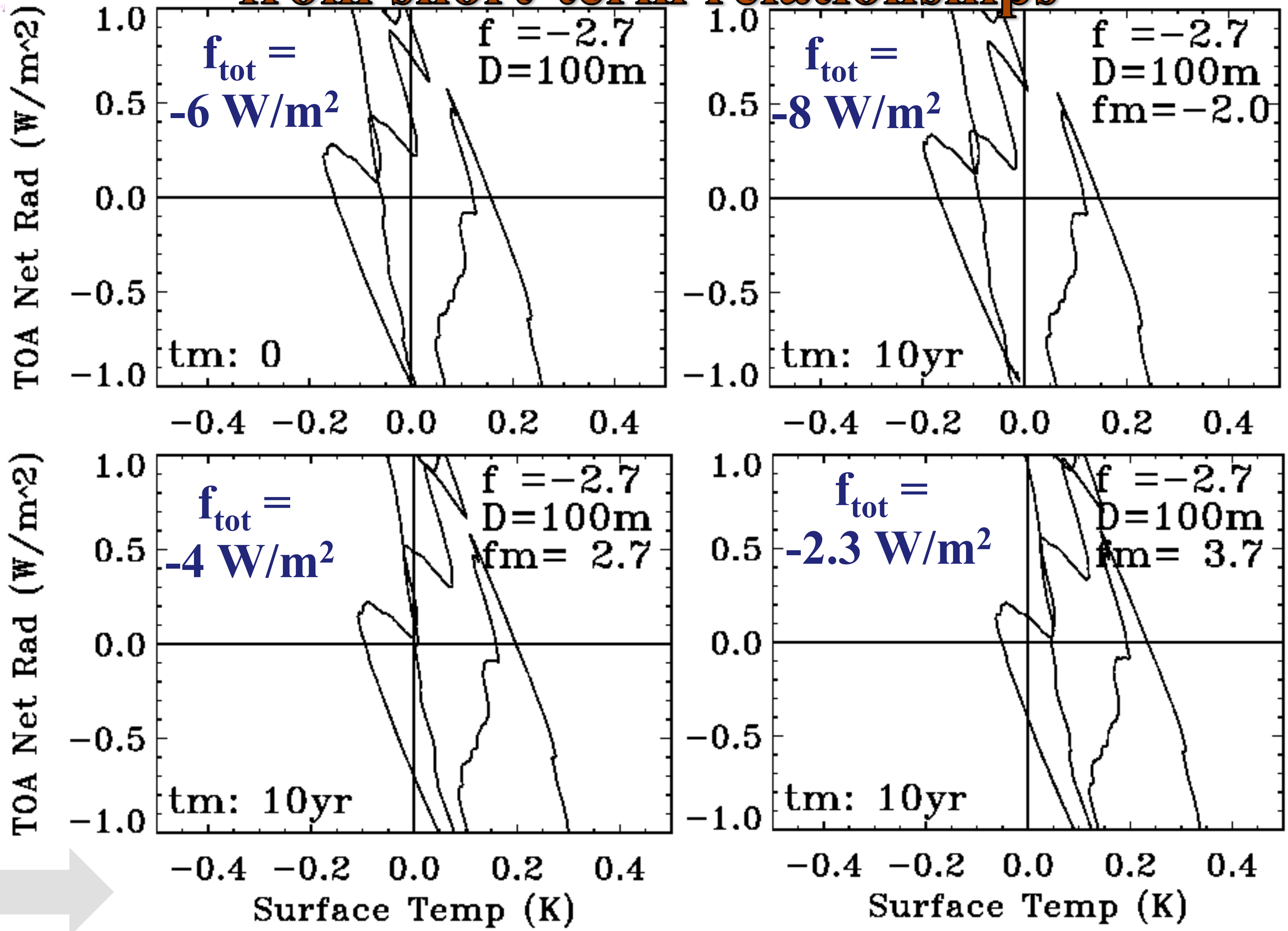
fn = -3.3 $Wm^{-2}K^{-1}$ (only for blackbody)

Feedbacks: this feature along with other processes.

Goals

- ➢ **Understanding radiation variations**
  - ❖ maintaining its base state: especially LW anomaly
  - ❖ relationship with other processes
- ➢ **Short-term phenomena**
  - ❖ long-term effect may not show up clearly
  - ❖ short-term feedback from dynamics/thermodynamics
- ➢ **Many controlling variables**

Cannot determine total feedback from short-term relationships



Goals

➢ Short-term phenomena

❖ long-term effect may not show up clearly
❖ short-term feedback from dynamics/thermodynamics

➢ Many controlling variables

❖ key parameters and variables for radiation:

skin temperature T; T gradient: ΔT_{LAT}, ΔT_{LON}
Column water vapor: CWV; Ozone: O_3
wind and wind divergence: $\underline{W}$, $\nabla \bullet \underline{W}$,
both linear and 2nd order variations:
e.g. CWV*W, $T\nabla \bullet \underline{W}$, $\Delta T_{LON} O_3$
total 35 variables/parameters/compound terms

Approaches

- 10-years CERES data: 2001 ~ 2010
  - TOA radiation fields & changes
  - anomalies of T and other variables
  - 'climatologies': ten-years means

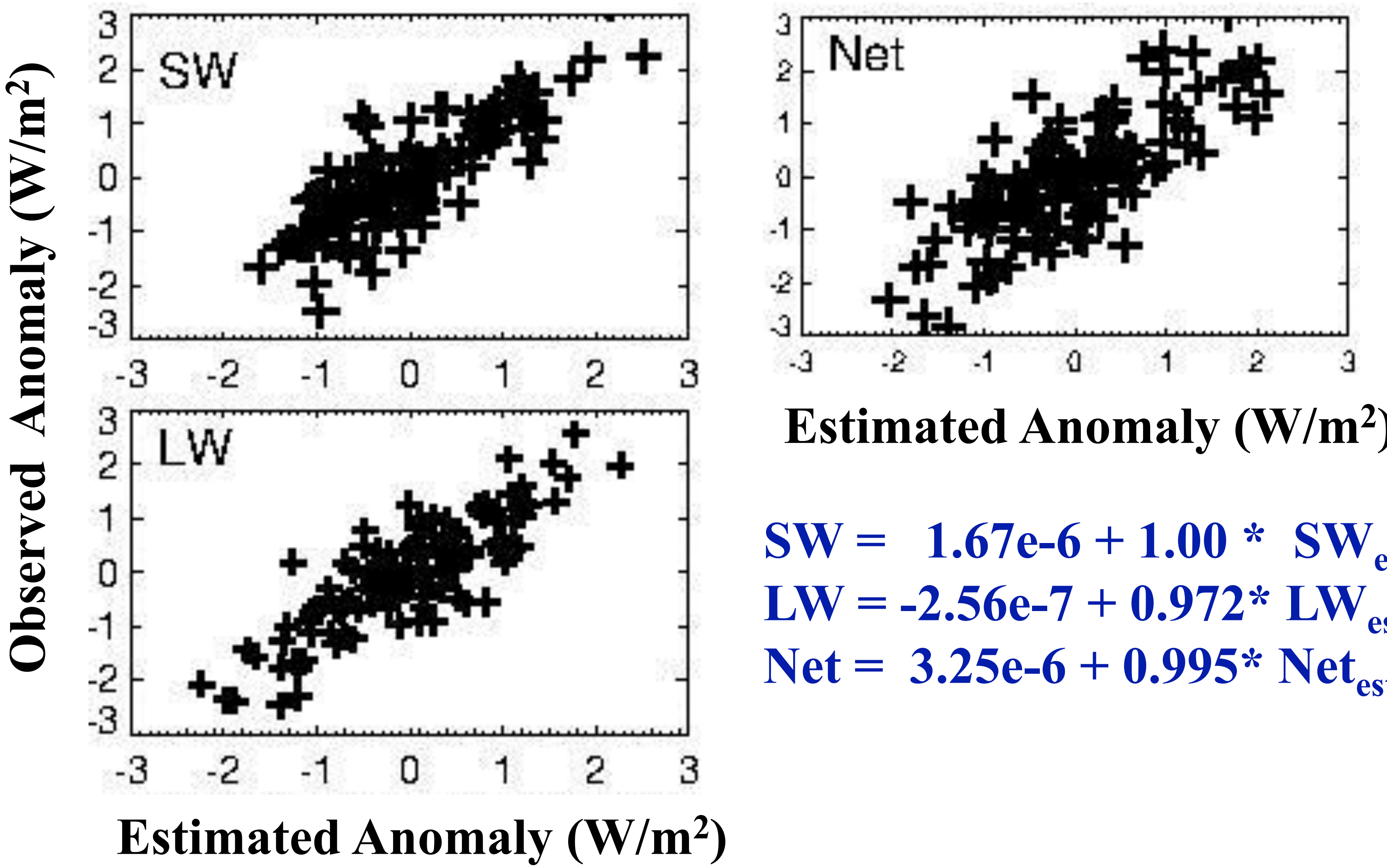
- Data Processing
  - tropical 23°S to 23°N zonal band
  - SSF1DEG monthly 1° × 1° grid boxes
  - multivariable linear regression

    eliminating statistically insignificant terms,
    until all terms are statistically meaningful
    empirically explain the anomalies in radiation fields

Results

- Time series
  - tropical monthly mean values: SW, LW & Net
  - Gridded results (shown some here)
  - statistical significant terms
  - high confidence on estimated results for the 10-yr data
- Surface temperature effects
- Water vapor effects
- Dynamics: ΔT_{lat}, ΔT_{lon}, W, $\nabla \bullet W$
- Other variables: e.g. ozone

Empirical Results



$SW = 1.67e\text{-}6 + 1.00 * SW_{est}$

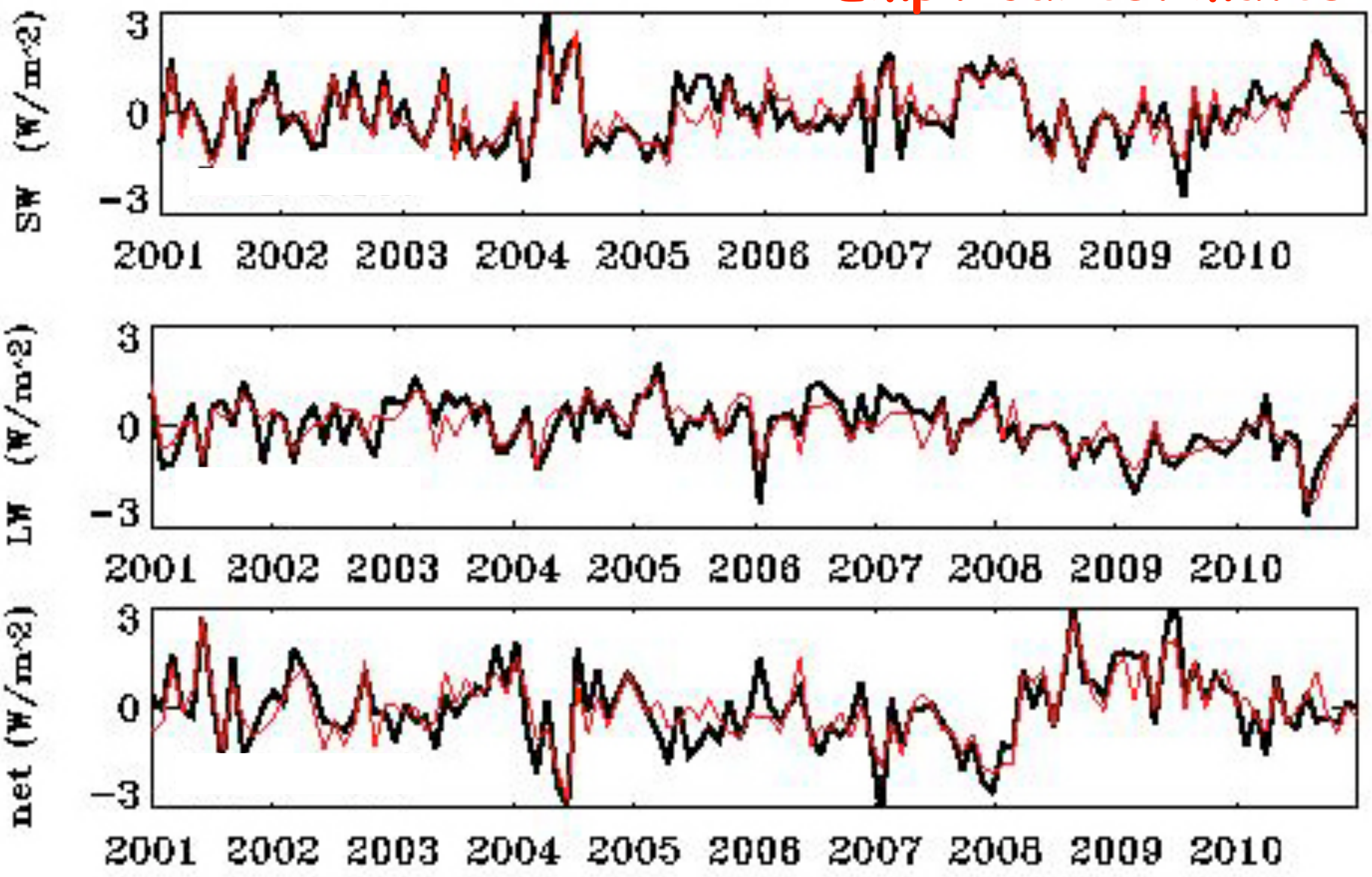
$LW = -2.56e\text{-}7 + 0.972 * LW_{est}$

$Net = 3.25e\text{-}6 + 0.995 * Net_{est}$

Tropical Mean Analysis

Observed anomalies

Empirical estimates



time (yr)

Results

- Time series
  - tropical monthly mean values: SW, LW & Net
  - statistical significant terms
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- Surface temperature effects
- Water vapor effects
- Dynamics: ΔT_{lat}, ΔT_{lon}, W, $\nabla \cdot W$
- Other variables: e.g. ozone

Multi-Variable Analysis for LW Radiation Anomaly

constant	V	W	∇_W	ΔT_{lat}	W^2	$\nabla_W{}^2$	$T{*}W$	$V{*}\Delta T_{lat}$	$W{*}O_3$	$\nabla_W{*}O_3$	$\nabla_W{*}\Delta T_{lon}$
2.83e-3											
coeff	-0.661	0.285	0.184	0.355	-0.143	-0.200	-0.245	0.178	-0.184	-0.214	0.201
corr	-0.449	0.049	0.037	0.141	-0.161	-0.184	-0.009	-0.023	-0.038	0.028	0.123
t_test	10.196	3.530	2.295	5.599	2.203	3.141	3.430	3.010	2.000	2.511	2.997

additional term: blackbody emission: fn*T

- temperature: blackbody emission; through water vapor
- water vapor: absorption/emission; UTH and clouds
- latitudinal temp. gradient: general circulation
- wind speed: through dynamics & clouds;

Multi-Variable Analysis for SW Radiation Anomaly

Const.	T	W	O_3	ΔT_{lon}	V^2	W^2	O_3^2	T*V	T*W	$T*\nabla_W$	V* ΔT_{lat}	V* ΔT_{lon}	ΔT_{lat} *ΔT_{lon}
8.0e-6													
coeff	-0.159	0.686	-0.273	0.197	-0.301	0.243	0.214	0.577	0.211	0.223	-0.297	0.459	-0.281
corr	-0.203	0.598	-0.122	0.188	0.140	0.232	0.055	0.099	0.001	0.174	0.017	0.080	-0.139
t_test	2.190	11.906	3.951	2.622	2.632	4.034	3.238	3.422	2.449	2.584	2.249	5.438	4.201

strong links to dynamics & thermodynamics

- wind speed: dynamics; storms; surface reflectivity
- ozone: SW absorption; tropo-strato-sphere interaction
- high order terms: additional dynamical impacts ??

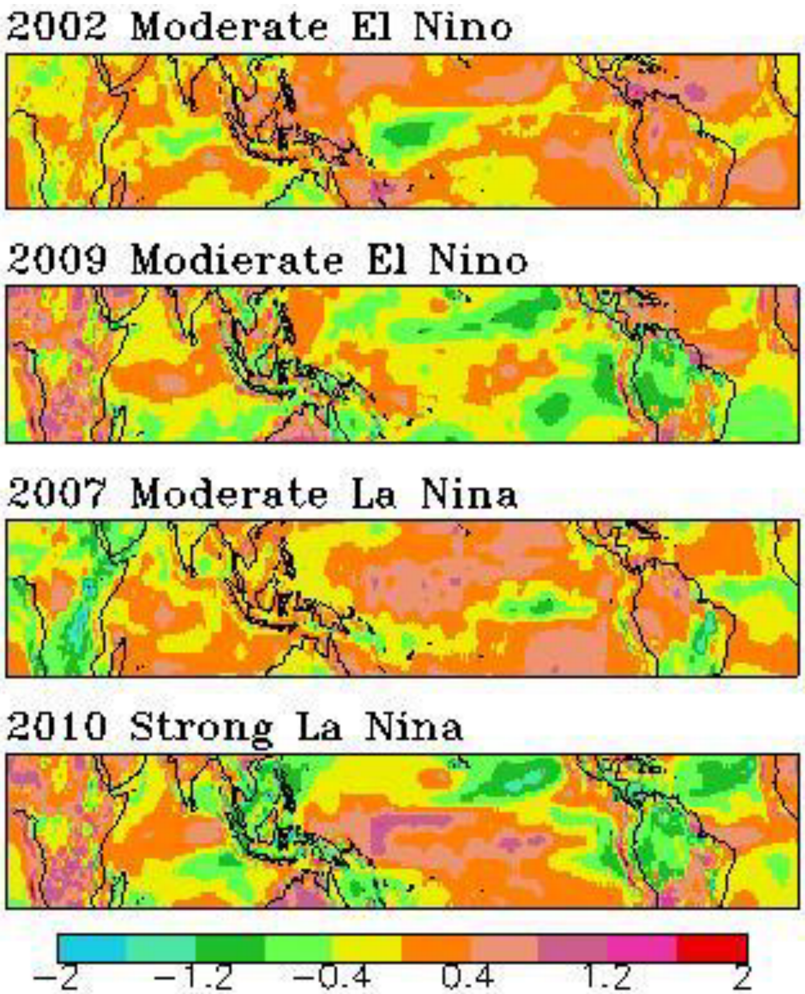
Multi-Variable Analysis for Net Radiation Anomaly

Const.	T	V	W	O_3	ΔT_{lat}	∇_W^2	O_3^2	$T*\nabla_W$	$T*O_3^2$	$T*$ ΔT_{lon}	$V*$ ΔT_{lon}	∇_W* ΔT_{lon}
-2.83e-3												
coeff	0.434	0.440	-0.772	0.364	-0.323	0.169	-0.356	-0.207	0.197	0.365	-0.375	-0.217
corr	0.283	0.150	-0.531	0.041	0.072	0.048	-0.111	-0.130	-0.068	0.175	0.093	-0.114
t_test	2.774	3.959	9.820	3.930	2.580	2.289	4.039	2.212	2.063	3.401	3.590	2.399

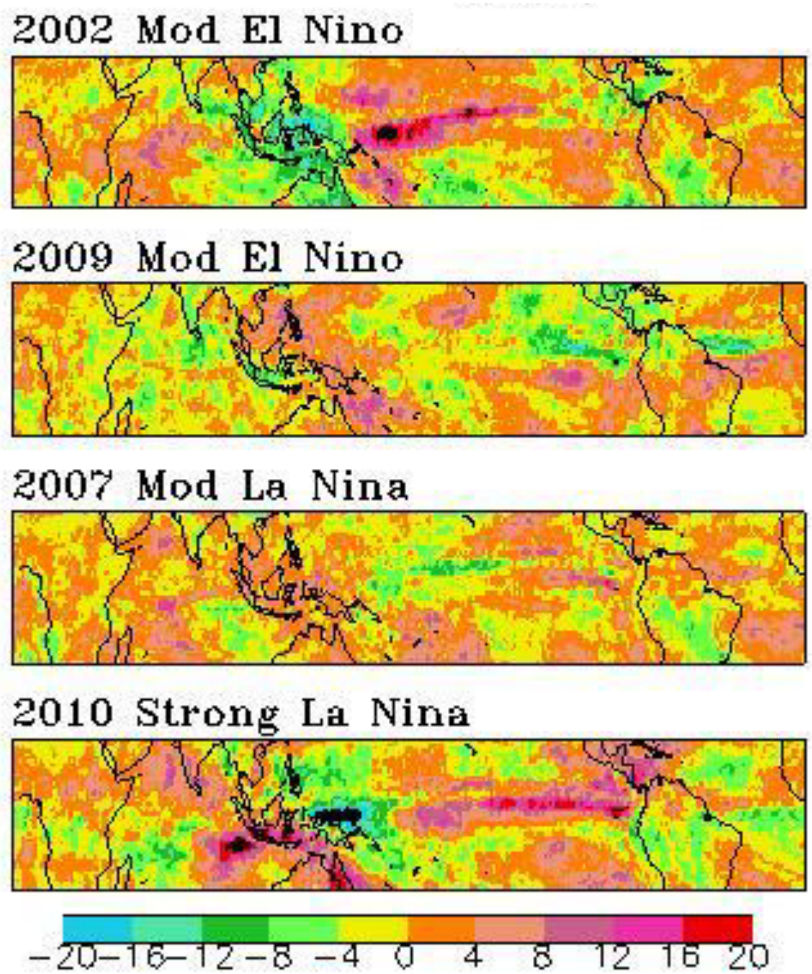
similar to LW or SW

- temperature: beyond blackbody emission;
- wind speed: dynamics; storms; both LW & SW
- water vapor: trap LW radiation; clouds with UTH
- ozone: shortwave absorption; interaction

Wind Speed and SW Anomalies

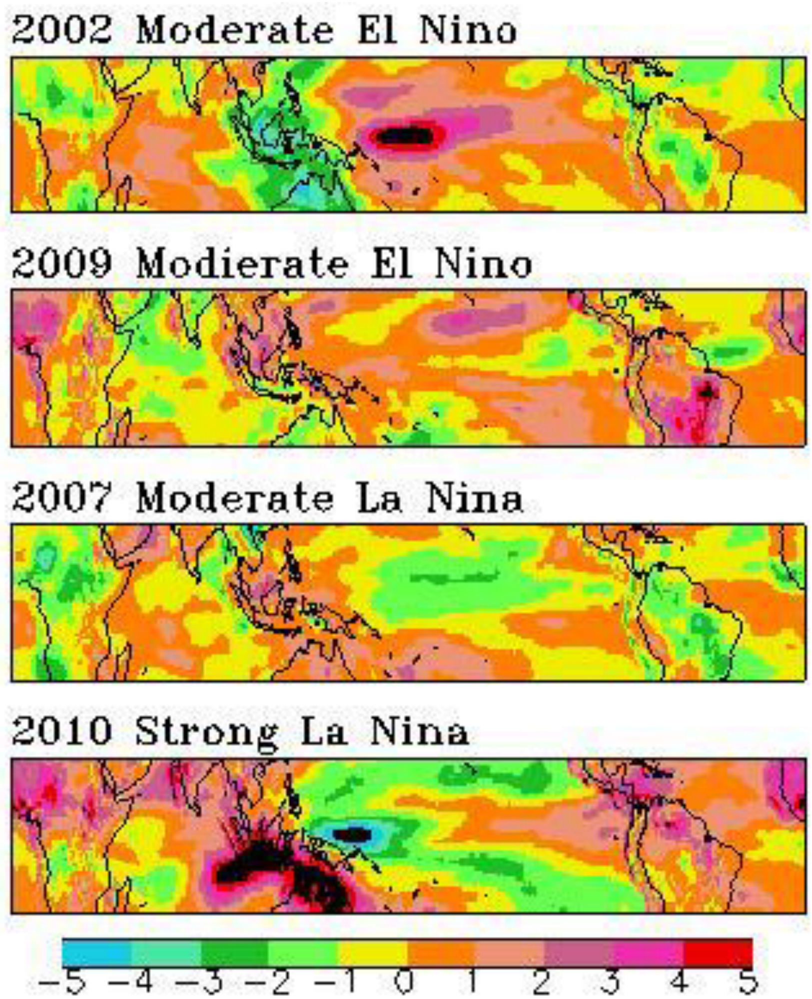


Wind Speed (m/s)

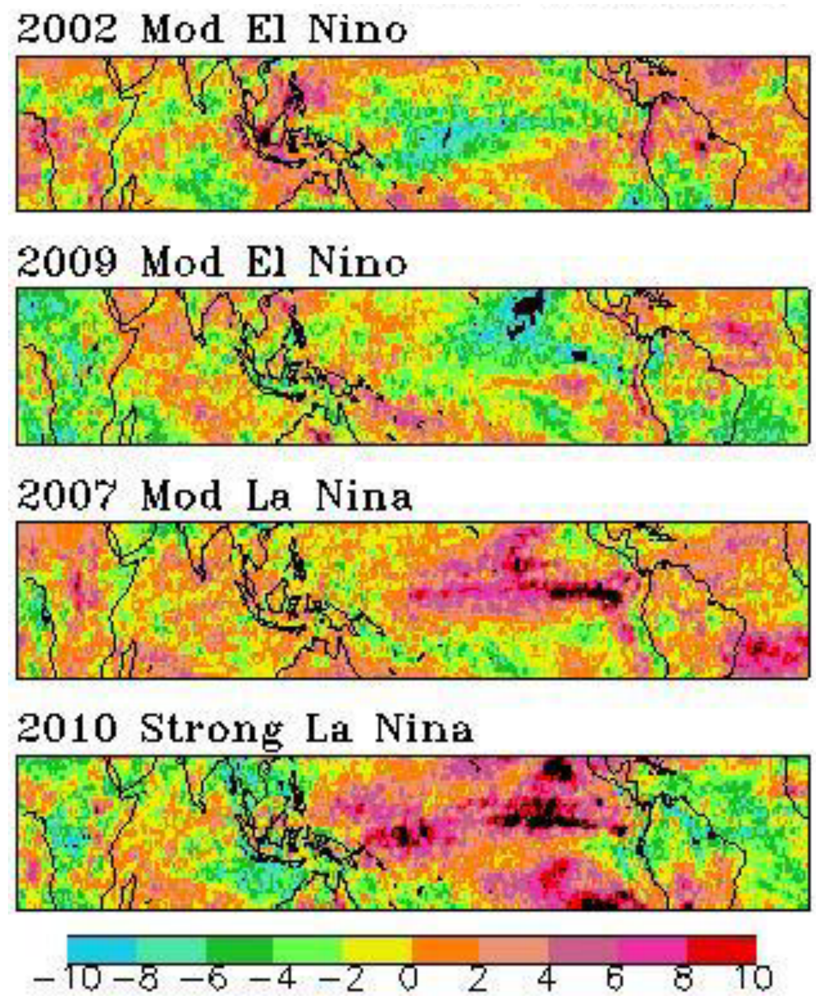


CERES Anomaly (W/m^2)

Water Vapor and Net Anomalies



Column Water Vapor (kg/m^2)



CERES Anomaly (W/m^2)

Short Term Feedbacks

- **LW (-)**
  - − : blackbody emission (or temperature) & dynamics
  - + : water vapor
  - others
- **SW (+)**
  - − : dynamics, especially along longitudinal direction
  - + : temperature & ozone (slow down dynamics ??)
- **Net (-)**
  - − : blackbody emission; dynamics
  - + : water vapor, temperature, ozone

Potential Long Term Impacts

Assuming with T increasing: V increasing, W decreasing, ΔT_{lon} decreasing

- **LW (-)**
  - - : blackbody emission
  - + : water vapor
  - ? : dynamics more likely (-)
- **SW (+)**
  - + : dynamics (slow down dynamics)
  - ? : ozone
- **Net (+)**
  - - : blackbody emission
  - + : water vapor, dynamics

Summary

- Short term radiation changes are one of the keys in maintaining climate basic states.
- Short term radiation variations with meteorological variables cannot be used to predict long-term climate feedbacks.
- The fundamental negative radiative feedback from blackbody emission is the neutral point of the climate system. Other feedback processes should be considered on top of this process.
- The tropical monthly means of water vapor, wind speed, ozone, and temperature gradients are by far the most important meteorological variables for radiation when the blackbody emission effect is removed.

Summary (conti.)

- High order terms of meteorological variables have significant impacts on radiation fields. More study on them is needed.
- Due to the average of entire tropics, wind divergence may not have a strong relation with radiative fluxes. Selection over certain areas may lead better results.
- Short term feedbacks for LW, SW and Net are likely negative, positive, and negative, respectively.

Thank You!